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Key Technical Approaches for Transitioning from Digital Manufacturing to Intelligent Manufacturing

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Abstract: Based on a comprehensive study of the implications and key techniques of intelligent manufacturing, this paper proposes three development models and specific technical approaches to facilitate China's transition from digital manufacturing to intelligent manufacturing. According to the production characteristics of a typical industry, the technical roadmap for realizing the transition from digital manufacturing to intelligent manufacturing is put forward. This roadmap provides guidance on the technical approaches that can upgrade China's manufacturing industry from digital manufacturing to intelligent manufacturing.

Keywords: digital manufacturing; intelligent manufacturing; technical approach; robot; roadmap

1 Introduction

As part of the "Made in China 2025" national strategic plan, the transition from digital manufacturing to intelligent manufacturing seems an inevitable trend in the rapid development of China's high-end equipment manufacturing industry, paving the way to realize China's transformation from simply a large manufacturing nation to a powerful one.

In recent years, China has made remarkable progress and breakthroughs in research and applications of digital manufacturing technology [1,2]. Digital manufacturing technology has become the core technology for solving high-end, sophisticated, and complex equipment manufacturing problems. At the same time, the research and application of intelligent manufacturing technology continue emerging [3–5]. Some manufacturing enterprise groups are actively adopting intelligent manufacturing technologies to enhance product intelligence. Intelligent production lines, workshops, and factories are rapidly emerging. Compared with industrially advanced countries, however, China is still in the process of transitioning from digital to intelligent manufacturing and this gap must be addressed.

In 2015, Deloitte and China Machinery Industry Federation conducted joint research on hundreds of intelligent manufacturing companies. The report shows that only 23% of Chinese companies have widely adopted intelligent manufacturing, indicating that the development of intelligent manufacturing is still at an early stage in China. Although application of intelligent devices in the automotive and parts industries exceeds 90%, they are seldom applied in other industries, particularly in machining and manufacturing industries (Fig. 1). The underlying reason for this gap includes lack of technical guidelines on transitioning from digital to intelligent manufacturing, which has slowed the progress of applying and promoting intelligent manufacturing.

Therefore, there is an urgent need to propose technical approaches for ungrading from digital to intelligent manufacturing and to build a technology roadmap for typical industries. This is significant in leading the development of mechanical manufacturing industry, thereby propelling China from simply a large manufacturing country to a powerful one and promoting product competitiveness in related industries within China.

2 Connotation of intelligent manufacturing

Intelligent manufacturing is the integration of both intelligent

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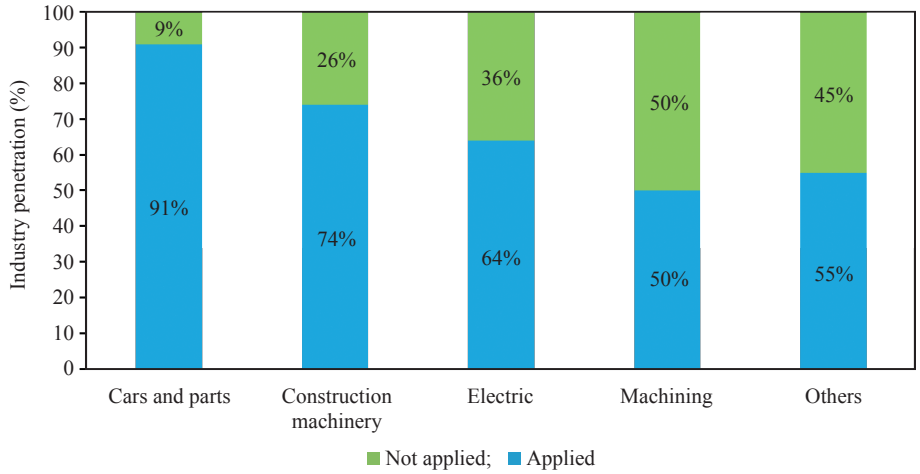

Fig. 1. Application of intelligent devices in China: Penetration by industry (2015).

and manufacturing technologies to solve manufacturing problems. It refers to knowledge representation and learning, information perception and analysis, and intelligent decision-making and execution of manufacturing activities throughout the full life cycle of products to realize knowledge inference, dynamic sensing, and autonomous decision-making regarding the manufacturing process, systems, and equipment.

Intelligent manufacturing involves all aspects of production, including intelligent design, processing, and assembly. Intelligent manufacturing involves intelligentization at three levels: manufacturing objects, manufacturing processes, and manufacturing tools. A knowledge base, dynamic sensing, and autonomous decision-making constitute the three core elements of intelligent manufacturing.

Intelligent manufacturing is a more advanced stage of manufacturing, and is realized based on digital manufacturing. Therefore, digital manufacturing technologies such as product data management, virtual manufacturing, rapid prototyping, computer-aided detection, and digital control are the basic technologies for intelligent manufacturing. However, intelligent manufacturing is based on knowledge and reasoning, whereas digital manufacturing is based on data and information processing. The fundamental differences between them are as follows:

(1) Digital manufacturing deals with data, whereas intelligent manufacturing deals with knowledge.

(2) Digital manufacturing mainly focuses on data processing, whereas intelligent manufacturing processing is based on new-generation artificial intelligence technology.

(3) Mathematical modeling in digital manufacturing is based on classical mathematical (calculus) methods, whereas in intelligent manufacturing, it is based on non-classical mathematical (intelligent mathematics) methods.

(4) Performance of digital manufacturing systems constantly degrades, whereas the performance of intelligent manufacturing systems can be continuously optimized.

(5) Digital manufacturing systems can not work properly when the environment is abnormal or misused, whereas intelligent manufacturing systems have fault-tolerance ability.

Intelligent manufacturing is the result of the continuous integration, development, and application of intelligent and manufacturing technologies. Intelligent methods such as data mining, machine learning, expert systems, neural networks, computer vision, Internet of Things (IoT), and cloud computing are integrated into manufacturing technologies such as product design, processing, and assembly to form various intelligent manufacturing technologies [6]. These technologies include knowledge representation and modeling, knowledge base construction and retrieval, heterogeneous knowledge transfer and sharing, real-time location, wireless sensing, dynamic navigating, and autonomous reasoning, compensation, and warning systems, as shown in Fig. 2.

By applying intelligent manufacturing technology to each manufacturing subsystem, the entire manufacturing system's automation and flexibility can be increased effectively. The main features of an intelligent manufacturing system built on intelligent technology are as follows:

(1) Intelligent perception. In intelligent manufacturing systems, manufacturing equipment can perceive their own working conditions and environment and can conduct intelligent analyses and decision-making based on their working conditions.

(2) Intelligent decision. An intelligent manufacturing system has the ability to analyze, judge, and make decisions based on the information collected by sensing. A strong knowledge base is an important support for intelligent decision-making capabilities.

(3) Intelligent learning. Intelligent manufacturing systems can perform data analysis and mining, and continuously improve the knowledge base through learning.

(4) Intelligent diagnosis. Intelligent manufacturing systems can monitor operating data, automatically diagnose and predict faults, and implement intelligent troubleshooting and repair.

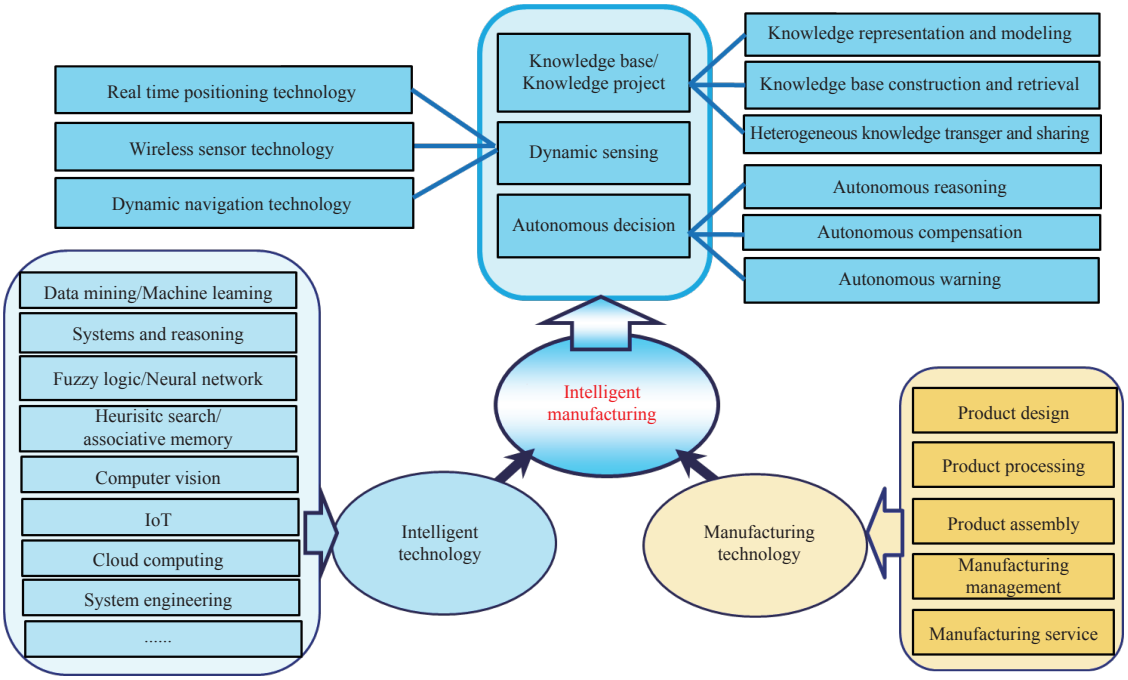

Fig. 2. Key technologies of intelligent manufacturing.

(5) Intelligent optimization. Intelligent manufacturing systems can adaptively adjust the structure and operating mode based on perceived information to ensure that the system's performance and efficiency are always in an optimal state.

3 Key technical approaches for transitioning from digital to intelligent manufacturing

3.1 Development modes

According to the characteristics and advantages of various industries and enterprises, the development modes from digital to intelligent manufacturing can be divided into the following three categories.

3.1.1 Based on the achievement of digital factories through digital manufacturing, intelligent factories and intelligent manufacturing are implemented sequentially.

The IoT and service Internet help strengthen information management and services in the product manufacturing process and improve the controllability of production process, and technologies such as big data and cloud computing help foster intelligent management and decision-making in the fabrication and assembly process and, ultimately, realize intelligent factories and manufacturing. Large enterprise groups with superior digital manufacturing infrastructures and strong information integration capabilities are suitable for the development from digital factories to intelligent factories. Through dynamic optimization of enterprise management and production process, the level of automation and intelligence in manufacturing is fully enhanced.

3.1.2 Digital manufacturing and intelligent manufacturing are developed simultaneously to realize informatization, digitization, real-time sensing, knowledge reasoning, and intelligent control, and thus achieve intelligent manufacturing.

Digital manufacturing technologies are developed and applied to achieve manufacturing informatization and digitization, and, meanwhile, intelligent manufacturing technologies are developed and applied to realize real-time sensing, knowledge reasoning, intelligence control, and autonomous decision-making regarding manufacturing equipment. Both the basic manufacturing equipment industry and specialized manufacturing equipment industry (including ultra-precision machining, machining of difficult-to-machine materials, machining of large parts, high-energy beam processing, and chemical polishing) are suitable for adopting this development approach.

3.1.3 Based on the digitization of unit technologies and processes, intelligentization of unit manufacturing followed by the intelligent manufacturing of the entire machine is achieved, and intelligent manufacturing is ultimately realized.

For highly complex and large-scale product manufacturing industries, such as large ships and commercial aircrafts, numerous product manufacturing units must be manufactured in a distributed and collaborative manner, and thus the development mode of intelligentization of unit manufacturing followed by the intelligent manufacturing of the entire machine is recommended.

3.2 Specific approaches

Based on the previous three development modes for

manufacturing companies across different industries, the following three specific approaches can be applied to advance from digital to intelligent manufacturing.

3.2.1 Achieve intelligent design, intelligent processing, intelligent assembly, intelligent services, and finally realize intelligent manufacturing.

As shown in Fig. 3, all steps in manufacturing process should be intelligentized, including the achievement of intelligent design, intelligent processing, intelligent assembly, intelligent management, and intelligent service, then intelligent manufacturing can be finally achieved.

3.2.2 Start with intelligentization of robotic assembly line operations to realize intelligentization of the material, information, energy, and capital flows within the manufacturing process.

Based on the intelligentization of robotic assembly line operations, a company's technological processes will be mechanized, automated, integrated, ecologicalized, and intelligentized with robots and automated control equipment, to achieve intelligence [7] in the material, information, energy, and capital flows of the manufacturing process. The realization of machine substitution can be achieved in four steps: machine-for-man, automatic-for-mechanical, complete set-for-unit set, and intelligent-for-digital, as shown in Fig. 4

3.2.3 Through the application and popularization of robots, robotic intelligence is improved so that robots will not only replace human physical labor but also partly replace the human brain.

Based on the breakthroughs in the independent development of core technologies and key components of industrial robots, the intelligent levels of industrial robots are expected to be enhanced, so as to simplify operation of robots, and ultimately to achieve robots with high intelligence which can complete assigned tasks without the need for advanced technical operations, as shown in Fig. 5.

4 Technology roadmap for developing intelligent manufacturing in a typical industry

Taking numerical control (NC) machine tools in the basic manufacturing equipment industry as an example, based on the technical research and the current situation and requirements of digital design and manufacturing in the NC machine tool industry, a technical approach of parallel development of digital

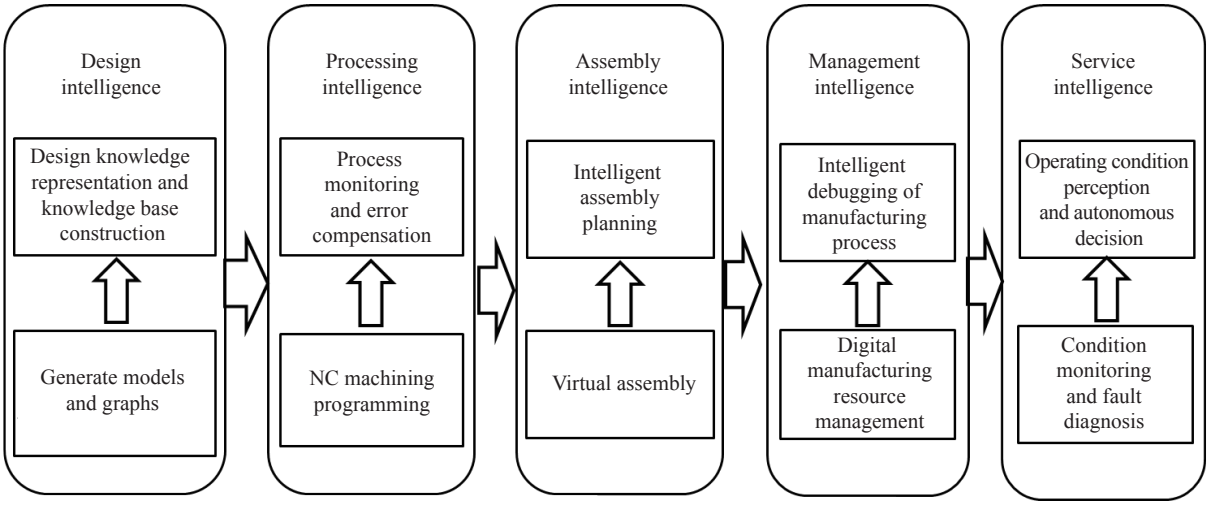

Fig. 3. Intelligence of manufacturing process.

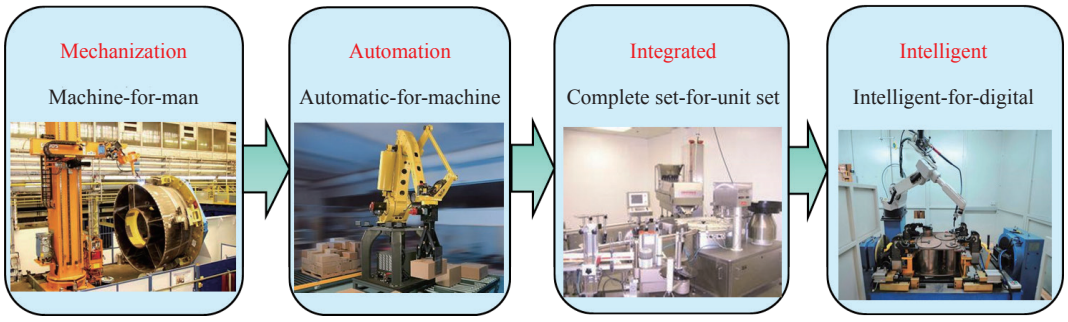

Fig. 4. Four-step approach in intelligent robotic line operations.

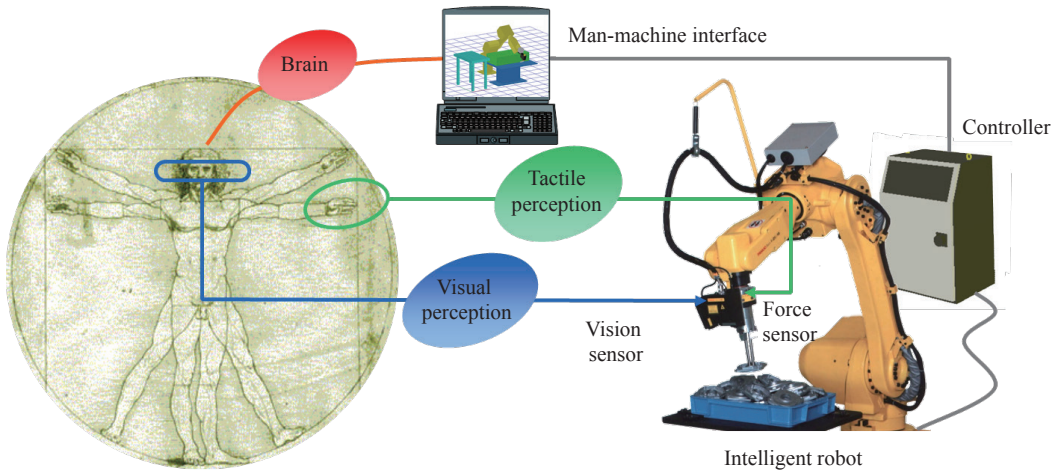

Fig. 5. Intelligent robot.

manufacturing and intelligent manufacturing is adopted, and a technical roadmap that meets the production characteristics of the industry and aims at developing from digital to intelligent manufacturing is formulated, as shown in Fig. 6.

To achieve the transition from digital to intelligent manufacturing, the NC machine tool industry should focus on the development of the following four key technologies:

(1) Big-data driven knowledge discovery and knowledge base construction techniques for NC machine tools. Using semantic analysis technology and a meta search engine, a detailed analysis and mining of the big data of NC machine tools is conducted to provide useful knowledge for NC machine tool design and manufacturing. Additionally, an NC machine design and manufacturing knowledge base should be constructed.

(2) NC machine tool operating condition real-time sensing technology based on distributed sensing. Sensors are embedded in the major components of NC machine tools, and the current operating conditions are sensed in real time based on the return data of the sensors and built-in intelligent algorithms.

(3) The NC machining system intelligent control technology based on IoT. Multiple NC machine tools with different machining characteristics are connected to form an intelligent control

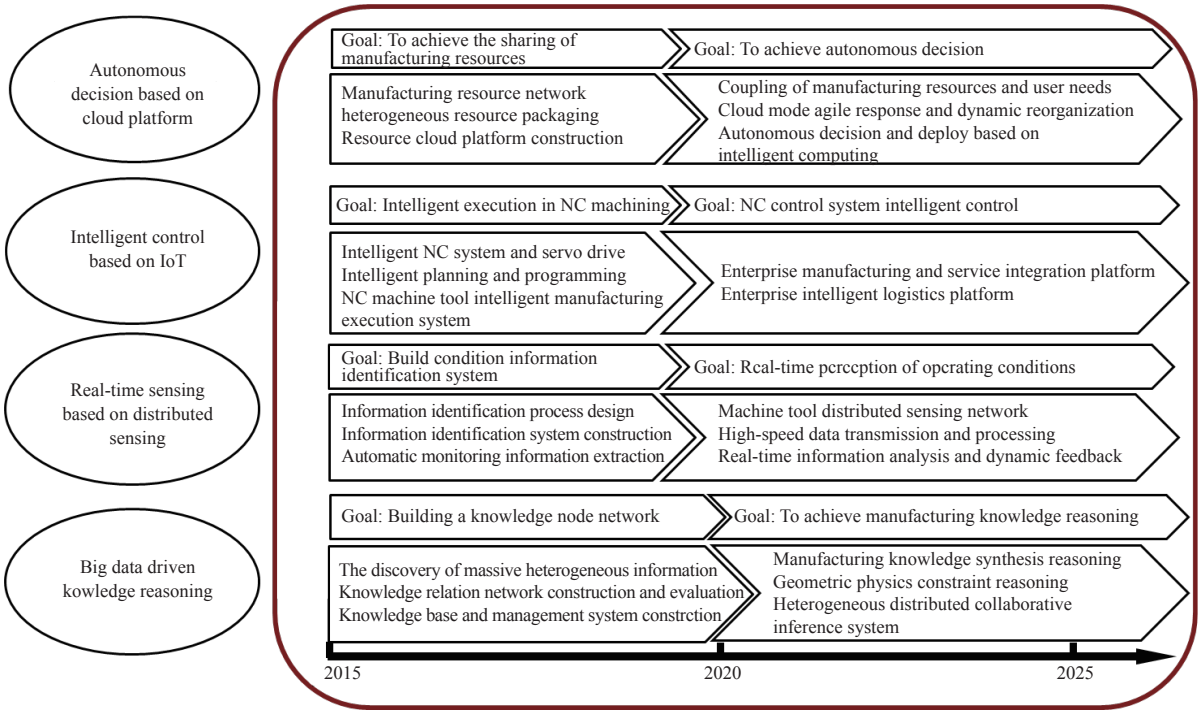

Fig. 6. Technical roadmap for NC machine tool industry developing from digital to intelligent manufacturing.

system to realize the intelligent identification, positioning, tracking, and management of NC machining equipment, as well as the real-time monitoring and intelligent control of NC machining systems.

(4) NC machine tool manufacturing resource autonomous decision-making technology based on cloud platforms. Based on end users' resource requirements for the cloud platform, design resources of NC machine tools are matched per the corresponding rules. According to the real-time status of the design resources of NC machine tools, autonomous decision-making regarding manufacturing resources can be achieved based on the cloud platform.

5 Conclusions

Due to the lack of specific technical guidance, China's progress in intelligent manufacturing is slow, and a large gap exists compared with other industrially advanced countries. Based on an in-depth study of the connotation of intelligent manufacturing, three major development modes for transitioning from digital to intelligent manufacturing in China, and the specific technical approaches for realizing the development are proposed. On this basis, according to the production characteristics of typical industries such as the NC machine tool industry, a technical roadmap from digital to intelligent manufacturing development is proposed.

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